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DEVELOPMENT OF A FACILITY MONITORING TESTBED

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ABSTRACT
The Advanced Surveillance Technology (AST) project at Los Alamos National Laboratory (LANL), funded by the Nonproliferation Research and Engineering Group (NN-20) of the National Nuclear Security Administration (NNSA), is fielding a facility monitoring application testbed at the National High Magnetic Field Laboratory–Pulsed Field Laboratory (NHMFL-PFL). This application is designed to utilize continuous remote monitoring technology to provide an additional layer of personnel safety assurance and equipment fault prediction capability in the laboratory. Various off-the-shelf surveillance sensor technologies are evaluated. In this testbed environment, several of the deployed monitoring sensors have detected transient precursor equipment-fault events. Additionally the prototype remote monitoring system employs specialized video state recognition software to determine whether the operations occurring within the facility are acceptable, given the observed equipment status. By integrating the Guardian reasoning system developed at LANL, anomalous facility events trigger alarms signaling personnel to the likelihood of an equipment failure or unsafe operation.

INTRODUCTION
By combining application-specific and commercial off-the-shelf (COTS) remote-monitoring surveillance technology a prototype remote facility-monitoring system is under development at the Los Alamos National Laboratory (LANL), site of the National High Magnetic Field Laboratory (NHMFL). The NHMFL is a three site research facility sponsored by the National Science Foundation (NSF). Each of the three sites provide users from around the world access to state-of-the-art equipment and techniques typically used for conducting low-temperature, condensed-matter physics research in either steady-state DC magnetic fields (Florida State University at Tallahassee), in Nuclear Magnetic Resonance (NMR) (University of Florida at Gainesville), or in pulsed-power, high-field magnets (Pulsed Field Laboratory (PFL) LANL). In order to provide the energy required to bring the pulsed-power magnets[1] to their peak fields, a capacitor bank capable of providing 1.6 Mjoules of energy is employed at the LANL-PFL facility.

The capacitor bank room provides a unique facility for the AST project where operational safety assurance may be improved using remote facility-monitoring technology. Two capacitor bank room operations have been selected for continuous surveillance. The first involves assessing the status of the manual discharge procedure upon initial personnel entry into the room. Monitoring this procedure with determination of the room status (discharged and powered down versus charged and powered up) provides the staff with equipment safety information previously unavailable without entry into the room. Second, the equipment within the room is monitored during normal operations for transient events. Information collected provides staff with early warnings of equipment failures.

The initial phase of the NHMFL Surveillance Project encompassed deployment of the surveillance sensors and equipment (cameras, passive infrared detectors (PIRs), door switch, microphones, rf) and collection of the operational data. The data collection phase produced:

- 117 hours of quad video/audio data,
- 105 hours of thermal imaging data,
- sensor (PIR/door switch) logs,
- 1100+ rf triggered events, and
- shot logs provided by the NHMFL.

The PIR detectors and the cameras have been able to detect and record transient arc events occurring within the room. These arc events are produced by capacitor bank equipment faults and destructive failures during normal operations. Previously, the equipment faults[2] had not been detectable until a destructive equipment failure occurred (Figure 1). Analysis of the AST data shows evidence that destructive failures follow several precursor events of lesser magnitude.

Figure 1. Example capacitor bank switch failure (switches provided by Multi-Contact USA).

The second phase of this remote facility-monitoring project involves the development of the full facility-monitoring system to notify staff (via local audio, email, and pager) in the event of a detected equipment fault or abnormal operating status. Classification systems are being developed and tested for audio, video, and rf systems to provide detailed event notification. A web-based interface provides event review with automatic sensor activity highlights and multimedia (audio and video) playback of event activity. NHMFL staff and visiting researchers are able to make a detailed review of equipment failures and initiate system modifications before destructive faults occur. Preemptive action has the potential for programmatic cost savings in equipment, maintenance, and personnel costs. From a safety perspective, this monitoring system provides further assurance that procedures are followed and provides additional facility state information not previously available.

FACILITY DETAILS

The NHMFL-PFL currently employs several layers of redundant features to assure the safety of its 10 kV, 1.6 MJ capacitor bank system. From detailed operator training, to the design of a mechanical interlock system for disabling the capacitor bank when personnel are in hazardous locations, safety is fully integrated with the standard operations of the facility. Beginning with an analysis of the physical safety systems and general procedures currently employed in the NHMFL-PFL facility, areas of operation where remote monitoring provides enhanced operational safety have been identified. The first of these areas of operation involves determining whether the capacitor bank is active or safe. Because residual charge may exist in the capacitors or a switch may have failed during standard bank operations, the capacitors must be manually discharged prior to unrestricted personnel access to the capacitor bank room. By monitoring the status of the grounding equipment within the room, the safe/active status of the bank is remotely determined. Unlike a mechanical interlock system that automatically dumps the bank under hazardous conditions, the procedure of grounding the bank is completely manual. Providing an alarm when the bank has not been properly deactivated increases the assurance of personnel safety in the facility.

The second area of operation that is remotely monitored in the laboratory involves the detection of arc events within the facility during standard charging cycles. Because the equipment within the facility is operated near its materials strength limits, destructive equipment faults are expected during standard operations. In general, such faults cause significant downtime at considerable facility cost. When typically undetected precursor arc events are identified by a remote monitoring system, the overall productivity of the laboratory is substantially improved.

EVALUATION OF COTS SENSORS

Many types of sensor technologies are currently available for surveillance applications. These include video cameras, acoustic sensors, thermal imaging cameras, as well as motion sensing units (Figure 2). The electromagnetic pulses (EMPs) produced during charge cycles in this application must be taken into consideration in all monitoring system designs. Additionally, because the capacitor bank has been designed to “float” relative to the building ground, the module frames may be at a 10 kV potential in certain load configurations. In order to ensure that the sensors themselves do not increase the likelihood of a fault, their placement must not be in direct contact with any equipment within the room and their signal and power lines must be isolated from power lines within the capacitor bank room.

Figure 2. Typical surveillance equipment.

A significant portion of this testbed application has involved evaluating various off-the-shelf sensors within the facility environment in an attempt to determine the appropriate elements and technology for the final remote-monitoring system. Table 1 lists the various data collected during an initial two-month sensor evaluation period. Specialized hardware and software synchronize the various input data streams. During this initial two-month period, ten transient events were recorded. Several of these events have been cross-correlated among the various sensor types. Table 2 highlights these events and the detecting sensors.

Table 1. Data Collected during the Initial 8-Week Technology Evaluation Period

Acoustic Data	117 hours digitized at 11025 Hz
Quad Video Data	117 hours
Infrared Thermal Imaging Data	105 hours
rf Antenna Data	3301 triggered waveforms
Sensor (PIR)/Magnet Shot Data	Annotated logs for the 963 magnet shots

Table 2. Breakdown of Recorded Arc Events

Magnet Shot Number	Magnet Field (Tesla)	Acoustic Sensor	Video Sensor	Thermal Imaging Video	PIR Sensor	rf Sensor	Catastrophic Equipment Failure (Y/N)
16740	60				X		Y
16753	60	X	X				Y
16765	58				X		Y
16818	58				X		N
16827	58				X		N
16829	58				X		N
16832	58				X		Y
----	58				X		Y
17303	58	X	X			X	N
17314	50	X	X	X			N

Video

In order to determine whether the capacitor bank is grounded and safe, the commercial ground rod and high voltage power supply (HVPS) switch positions in the capacitor bank room must be remotely determined. Four CCD cameras are fielded to remotely monitor the positions of the equipment within the room. In general, the operational EMP within the room does not significantly alter the image stream analyzed. However, the single-cable power translators initially deployed with the cameras were adversely affected by the electrical environment and had an average operational lifetime of two weeks in the capacitor bank room.

Acoustic/Audio
An inexpensive omni-directional acoustic sensor (microphone), sensitive to frequencies in the range of 30 to 3000 Hz, is fielded within the bank room to collect audio events. Preliminary analysis indicates that the sensor is robust to the adverse EMP conditions of the environment. Distinct audio events have been recorded in the room when the equipment arcs occur. A discrimination system is currently under development for use in the detection of these events.

Passive Infrared Detectors
Several passive infrared detectors (PIRs) are installed in the capacitor bank room. Unexpectedly, the PIR detectors have been sensitive to the transient arc and equipment fault events and trigger (on/off signal) with a fast response time to these events.

Radio-Frequency (rf) Emission Detectors
A single-channel noise-riding rf detector has been designed and built for this application. This detector is tuned to detect anomalous rf events in the range of 20 to 300 MHz in the facility.

Infrared Thermal Imaging Video
An Inframetrics 760 infrared thermal-imaging video camera was positioned within the capacitor bank room during the initial sensor evaluation phase. The high cost of the unit precluded the deployment of additional units. Of the ten arc events recorded, only one has been captured by the thermal imaging camera, and because of the poor recorded fidelity of the event, the camera has been abandoned for this application.

REMOTE-MONITORING SYSTEM DEVELOPMENT
The remote-monitoring system development began once the collected data from the initial sensor deployment was analyzed. Tying together the heterogeneous data collected by the video, acoustic, PIR, and rf sensors is Guardian, the LANL rule-based reasoning system (Figure 3). This reasoning system acts as the top-level decision engine. Because the arc events signaling equipment failures are typically only captured on a single video frame (collected at a 30-frame-per-second rate), video analysis is strictly used to classify the equipment state within the capacitor bank room. This information is indicative of the facility status (disabled or active) and may be used by Guardian to set alarms when anomalous activities are detected.

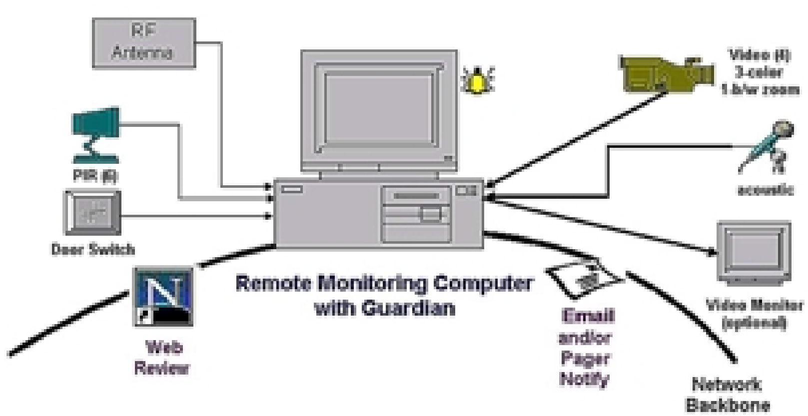

Figure 3. Prototype Remote Facility Monitoring System.

The detection of transient events is the focus of the PIR, rf and acoustic systems. Because the inexpensive PIR detectors demonstrate an ability to reliably trigger on equipment arcs, they are the primary indicator of facility equipment failures. Additionally, the rf detector is designed to send a signal to Guardian when the detected signal is above an adjustable noise threshold indicating an event. Similarly, an acoustic event detector is under development to trigger Guardian when the acoustic signal rises above an adjustable threshold.

The role of Guardian in this application is to fuse the heterogeneous information from the fielded sensors and produce a reliable decision about the facility's state. When anomalous events or activities are detected, Guardian sends alarms locally and alerts via email and pager the NHMFL-PFL staff. A web-based interface provides event review including sensor activity highlights and video playback of the activity in the capacitor bank that triggered the event.

CONCLUSIONS

In the first few days of field operations, the PIR sensors triggered four times in a 6-hour period during charging cycles (see Table 2, shots 16818, 16827, 16829, 16832). The final transient event destroyed a capacitor bank. From that experience, the Guardian reasoning module was modified for the fielded system to alert the NHMFL-PFL staff, using local alarms, to these precursor equipment fault events. The deployed sensors and the Guardian module have since detected precursor faults and provided alarms to facility staff. On-going research and development efforts into the individual sensor classification systems provide enhanced discrimination and detection capabilities. The result of this final project phase is a prototype remote-monitoring system that notifies staff of potentially dangerous activities or anomalous events. With the information provided by the web-based interface, the NHMFL-PFL staff are able to make a detailed review of precursor indicators to avoid equipment faults. The NHMFL-PFL loses an average of 5 to10 days per year to catastrophic equipment failure (facility reliability is 96 to 98%). Remote monitoring sensors, which are able to predict faults before significant damage occurs, provide cost savings to the facility. The modular technologies developed and demonstrated may be applied in diverse surveillance applications to improve safety and reliability.

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